

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. XXXVIII. SUPPLEMENTARY NOTICE. No. 9.

On the Measurement of the Inequality of Pivots of Transit Instruments by means of the Spherometer.

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In the autumn of 1875 it became necessary to determine the inequality of pivots of the eight Transit Instruments which had been used by the United States transit of *Venus* parties; and to have done this in the ordinary way, by means of the spirit level, would have occupied not less than three weeks. This was more time than I could conveniently spare for the purpose, and after some thought I contrived an instrument with which the required determinations were most accurately made, and the time expended was only an hour for each transit. This instrument was first tried on February 28, 1876, and as some copies of it have already been made for other astronomers, and it seems to be coming rapidly into use in the United States, perhaps a detailed description of it may be acceptable to the Royal Astronomical Society.

The spherometer-caliper, for such is the name of the instrument, is shown in the accompanying plate: fig. 1 being a front elevation; fig. 2 a side elevation; fig. 3 a plan; and fig. 4 a section through the point *f*, fig. 1. The lettering is the same on all the figures. The foundation plate, *b*, of the instrument carries two cylindrical guides, *d*, *d*, which are connected at their lower ends by the bar *e*. Into the foundation plate is screwed the brass piece *m*, to which is cemented the thick circular glass plate *c*. The two Ys, *a*, *a*, are also firmly screwed to the foundation plate. The brass plate *f* slides freely up and down between

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THE SPHEROMETER CALIPER.

Fig. 1.

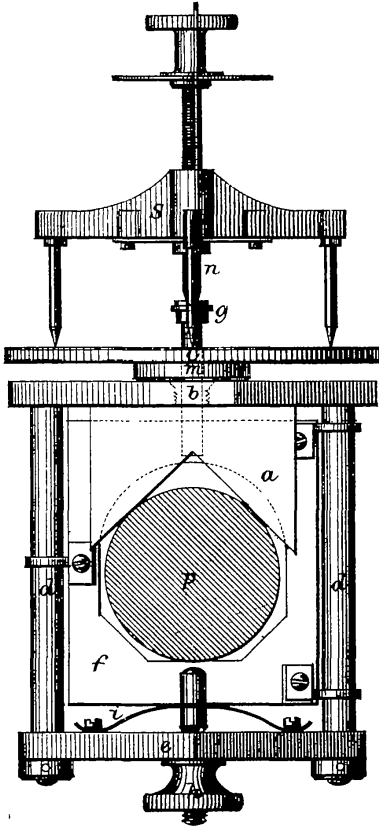


Fig. 2.

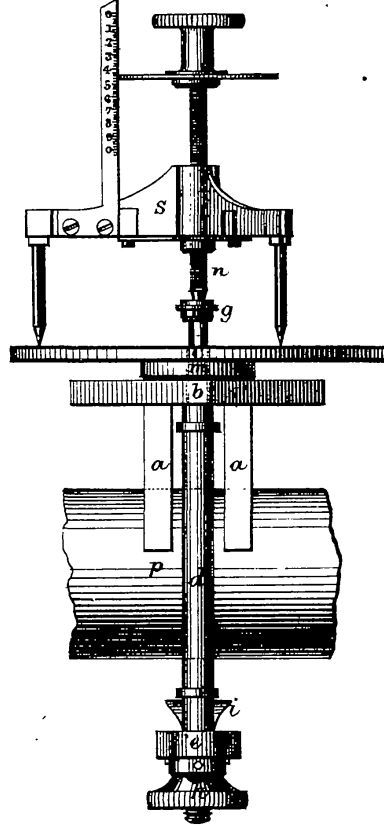


Fig. 3.

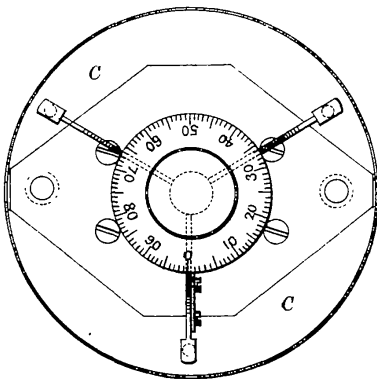
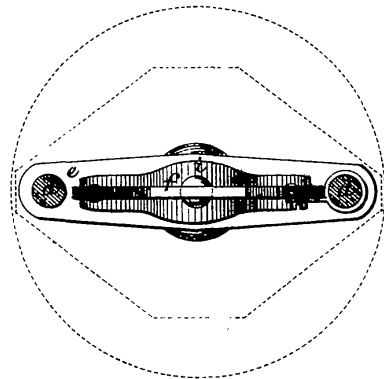


Fig. 4.



Scale



Spottiswoode & Co. Lith. London.

the guides d, d ; being kept in their plane by three loops, two of which pass around the right-hand guide, and one around the left-hand guide, as shown in the figure. The brass rod g , which passes through the piece m and the plate c without touching either of them, is firmly attached to the upper end of the plate f , and moves with it; while to the lower end of f is attached a second short brass rod which passes freely through the bar e and carries the nut h . There is an aperture in the plate f sufficiently large to permit the free passage of such transit pivots as the caliper is intended to measure.

In using the instrument the plate f is depressed by means of the nut h until p , one of the pivots whose inequality is to be measured, passes freely under the Ys, a, a . Then, the Ys having been properly adjusted upon the pivot, h is loosened, and the flat edge of the aperture in f is forced against the under side of the pivot by the spring i . Finally, the elevation of the end of the rod g above the glass plate c is accurately measured by means of a small spherometer. This process having been repeated upon the other pivot, the inequality of the two pivots will evidently be a function of the difference of the two readings of the spherometer. To insure the greatest possible accuracy of measurement, the glass plate c must be entirely free from strain, and the flat surface of the opening in f must be pressed with the same degree of force against the under surfaces of the two pivots. Both these conditions are evidently fulfilled in the construction of the instrument; and, as an additional precaution, the top of the rod g is capped with a carefully ground agate, upon which the point of the spherometer screw rests.

To find the relation between the difference of the two readings of the spherometer and the inequality of the pivots upon which they were made, put

$2i$ = the angle of the Ys of the caliper :

n = the difference between the readings of the spherometer on the two pivots :

R = the linear value of one revolution of the spherometer screw :

l = the distance between the pivots of the transit instrument :

p = the inequality of pivots; expressed in seconds of time, and to be considered positive when the eastern pivot is the largest,

Then, if the radius of the pivot undergoing measurement is r , the vertical distance from the angle of the Ys to the centre of the pivot will be $\frac{r}{\sin i}$; and the vertical distance from the centre of the pivot to the flat surface of the aperture in f will be r . Hence, if the vertical distance from the upper surface of the glass plate c to the angle of the Ys is C , the vertical distance from the upper surface of c to the flat surface of the aperture in f will be

$$C + r + \frac{r}{\sin i} = C + r \left(\frac{1 + \sin i}{\sin i} \right). \quad (1)$$

Similarly, for the other pivot, whose radius is r' , the distance will be

$$C + r' \left(\frac{1 + \sin i}{\sin i} \right). \tag{2}$$

The difference between (1) and (2) is

$$(r - r') \left\{ \frac{1 + \sin i}{\sin i} \right\} \tag{3}$$

which is the space moved through by the plate f when the second pivot was substituted for the first. As the plate f carried the rod g with it, this space must be equal to the linear value of the difference of the readings of the spherometer upon the two pivots. Hence

$$(r - r') \left\{ \frac{1 + \sin i}{\sin i} \right\} = nR, \tag{4}$$

and therefore

$$r - r' = \frac{nR \sin i}{1 + \sin i}, \tag{5}$$

which is the inequality of pivots, expressed linearly. To convert it into seconds of time it must be divided by $l.15 \tan 1''$, and thus we obtain finally

$$p = n \frac{R \sin i}{l (1 + \sin i) 15 \tan 1''}. \tag{6}$$

By the kind permission of the Superintendent of the U.S. Naval Observatory, I am enabled to give some examples of the actual working of the spherometer-caliper. The first is the measurement, made March 20, 1876, of the inequality of pivots of the portable transit instrument, Stackpole & Bro., No. 1502.

Position of Pivot.	Clamp Pivot. r	Lamp Pivot. r	n. r	p. s
180°	43°55'1	43°53'9		
	55°0	54°0		
	54°9	54°0		
	43°55'00	43°53'97	0.0103	0.031
225	43°54'9	43°53'6		
	55'1	54°0		
	55'1	54°0		
	43°55'03	43°53'87	0.0113	0.034
				0 0 2

Position of Pivot. o	Clamp Pivot. r	Lamp Pivot. r	n. r	p. s
270	43'551	43'540		
	551	539		
	550	540		
	43'5507	43'5397	0'0110	0'033
315	43'548	43'540		
	552	540		
	553	541		
	43'5510	43'5403	0'0107	0'032
Mean value of p = 0'032				

Four diameters were measured in each pivot, their positions being indicated by the readings of the finding circle, which are contained in the first column of the table above. The readings of the spherometer upon the clamp pivot are contained in the second column, those upon the lamp pivot in the third column ; and the resulting values of *n* and *p* are given in the fourth and fifth columns. The mode of measuring each diameter was as follows: The transit instrument being upon its reversing carriage, so that the pivots were entirely free, the axis was turned until that diameter of the pivot which it was desired to measure was vertical. Then the caliper was slipped on to the pivot and adjusted so that the surface of the plate *c* was perfectly level, after which the spherometer was placed upon it and very carefully read. This process was repeated three times; the caliper being removed from the pivot after each reading, so as to render the readings as independent of each other as possible. The value of *n* for any given diameter was, of course, the difference between the mean of the three readings upon the clamp pivot and the mean of the three corresponding readings upon the lamp pivot. To find *p* we require certain constants, the values of which in the present instance are

$2i = 90^{\circ}, \quad R = 0.02697 \text{ cm.}, \quad l = 50.65 \text{ cm.}$

Substituting these values in equation (6), we obtain

$$p = 3.033n,$$

and accordingly, the values of *p* in the table above have been obtained from those of *n* by multiplying the latter quantities by 3.033. A comparison of the numbers in the second and third columns shows that the clamp pivot is the largest.

Our second example of the working of the spherometer-caliper is the measurement, made February 18, 1878, of the inequality of pivots of the portable transit instrument, Stackpole & Bro., No. 1506.

Position of Pivot.	Clamp Pivot.	Lamp Pivot.	$n.$	$p.$
$^{\circ}$	r	r	r	s
180	43'237	43'218		
	'232	'219		
	'235	'217		
	43'2347	43'2180	0'0167	0'051
225	43'235	43'222		
	'238	'221		
	'238	'224		
	43'2370	43'2223	0'0147	0'045
270	43'237	43'215		
	'235	'219		
	'238	'218		
	43'2367	43'2173	0'0194	0'059
315	43'236	43'216		
	'239	'216		
	'238	'211		
	43'2377	43'2143	0'0234	0'071
Mean value of $p =$ 0'056				

Upon reducing these measurements, my first impression was that the large value of p at 315° must have been erroneous, and I remeasured the pivot inequality at that point, with the result, $p = 0'075$. This confirmed the first measurement, and showed beyond all possibility of doubt that one, or perhaps both of the pivots were elliptical. An examination of the spherometer readings upon the clamp pivot proves that it is round, at least within the limits of error of observation; but with the lamp pivot the case is different. The largest spherometer reading upon it is at 225° , and the smallest at 315° . These are therefore the approximate positions of the major and minor axes of the ellipse. The difference of the spherometer readings at these points is $0'0080$. Substituting this in equation (5), we find

that the semi-major axis exceeds the semi-minor one by 0.000089 cm.—a small quantity truly, but one about which there can be no mistake. This degree of ellipticity is so slight that it may be neglected in a portable instrument, and accordingly we adopt the mean value of p , which is 0.056; the clamp pivot being the largest.

More examples might be given, but the above suffice to show that, for measuring pivot inequalities, the spherometer-caliper possesses the following advantages over the spirit level:—1st, It is more accurate; 2nd, it shows the exact form of each pivot; 3rd, it is at least ten times more expeditious.

To secure the advantage of accuracy to its fullest extent the following points must be attended to:—1st, The spherometer must be as light as possible: the one shown in the plate weighs only 37.10 grammes; 2nd, the screw of the spherometer must be entirely free from dead motion; 3rd, the surface of the glass plate c must always be truly levelled before applying the spherometer to it. In a properly constructed instrument there should be no difficulty about the second of the above conditions, but unfortunately few spherometers are properly constructed. The makers generally provide some means of tightening the main nut, thinking in that way to destroy the dead motion; but if any serious attempt is made to use this arrangement, it will be found that long before the dead motion disappears, the motion of the screw becomes so stiff as to render the instrument totally unmanageable. In my own instrument, immediately below the main nut there is a supplementary one with three elastic arms, which are attached to the frame of the instrument in such a manner that any required strain can be put upon them. The spherometer screw passes through both these nuts, and by carefully adjusting the tension on the arms of the supplementary one, which is two or three threads below the other, the two can be so pressed toward each other as to eliminate all dead motion, and yet leave the movement of the screw as light as may be desired. The importance of the third condition mentioned above depends upon the fact that all well-made spherometers are so balanced that when they stand upon a level surface their centre of gravity is in the screw. Consequently, when the screw comes in contact with the object to be measured, the three feet of the instrument will lift simultaneously if it is standing upon a level surface, but if it is standing upon a surface ever so little inclined, there will be a tendency for one foot to lift before the others, and the accuracy of measurement will be greatly impaired.

The spherometer-caliper shown in the drawing which accompanies this paper is the first one ever constructed, and as it is not furnished with any means of varying the size of the aperture in the plate f , it is only applicable to pivots whose diameter is not far from 3.40 cm. In a much larger instrument, recently made for Professor C. A. Young, of Princeton College, the flat edge of the aperture in the plate f consists of a bar which can be

adjusted to any desired height upon the plate, and thus the instrument is rendered capable of measuring pivots of almost any size.

Washington, 1878, May 22.

Spectroscopic Results for the Motions of Stars in the Line of Sight, made at the Royal Observatory, Greenwich. III.

(Communicated by the Astronomer Royal.)

The Results for Star Motions here given are in continuation of those printed in the *Monthly Notices* for 1876, May and November, and the general arrangement is the same.

Up to 1877, May 2, the observations were made with the ten-prism spectroscope (two or four prisms only being used for star work), and the method of observation has been sufficiently described in preceding communications. On 1877, August 23, the half-prism spectroscope was brought into use, but the observations suffered interruption during the oppositions of *Mars* and *Saturn*, and it was not till 1877, November 14, that this work was again brought into regular train. The principle of the new spectroscope is fully described in a paper in the *Proceedings of the Royal Society*, No. 179, 1877; and it may be sufficient to state here that the full train consists of two compound half-prisms, each being the half of a direct-vision prism, cut in two by a plane perpendicular to the base. Either one or two of the half-prisms can be used at pleasure: with one half-prism a dispersion of 20° from A to H, equivalent to four prisms of 60° , is obtained; and with two half-prisms a dispersion of 75° from A to H, equivalent to fifteen prisms of 60° . The number of half-prisms used is denoted by the Roman numerals I and II. The full dispersion of 75° , which is far greater than any hitherto used for stellar observations, has been applied recently to some of the brighter stars, including one of the second magnitude, and no difficulty has been experienced in making satisfactory comparisons with this high power. As a check against possible instrumental error arising from maladjustment of the spectroscope, comparisons have been regularly made, either before or after the observations, with the spectrum of the Moon or with that of the sky, the results of which are given at the end of the table.